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## 1. algorithm

#include <algorithm> #include <numeric>

Algo	Params	Funcion
sort, stable_sort	f, l	ordena el intervalo
nth_element	f, nth, l	<i>void</i> ordena el n-esimo, y particiona el resto
fill, fill_n	f, l / n, elem	<i>void</i> llena [f, l) o [f, f+n) con elem
lower_bound, upper_bound	f, l, elem	<i>it</i> al primer / ultimo donde se puede insertar elem para que quede ordenada
binary_search	f, l, elem	<i>bool</i> esta elem en [f, l)
copy	f, l, resul	hace resul+i=f+i $\forall i$
find, find_if, find_first_of	f, l, elem / pred / f2, l2	<i>it</i> encuentra i $\in [f, l)$ tq. i=elem, pred(i), $i \in [f2, l2)$
count, count_if	f, l, elem/pred	cuenta elem, pred(i)
search	f, l, f2, l2	busca $[f2, l2) \in [f, l)$
replace, replace_if	f, l, old / pred, new	cambia old / pred(i) por new
reverse	f, l	da vuelta
partition, stable_partition	f, l, pred	pred(i) ad, !pred(i) atras
min_element, max_element	f, l, [comp]	<i>it</i> min, max de [f, l]
lexicographical_compare	f1, l1, f2, l2	<i>bool</i> con $[f1, l1]_i [f2, l2]$
next/prev_permutation	f, l	deja en [f, l) la perm sig, ant
set_intersection, set_difference, set_union, set_symmetric_difference,	f1, l1, f2, l2, res	[res, ...) la op. de conj
push_heap, pop_heap, make_heap	f, l, e / e /	mete/saca e en heap [f, l), hace un heap de [f, l)
is_heap	f, l	<i>bool</i> es [f, l) un heap
accumulate	f, l, i, [op]	$T = \sum / \text{oper de } [f, l)$
inner_product	f1, l1, f2, i	$T = i + [f1, l1) \cdot [f2, \dots)$
partial_sum	f, l, r, [op]	$r+i = \sum / \text{oper de } [f, f+i) \forall i \in [f, l)$
__builtin_ffs	unsigned int	Pos. del primer 1 desde la derecha
__builtin_clz	unsigned int	Cant. de ceros desde la izquierda.
__builtin_ctz	unsigned int	Cant. de ceros desde la derecha.
__builtin_popcount	unsigned int	Cant. de 1's en x.
__builtin_parity	unsigned int	1 si x es par, 0 si es impar.
__builtin_XXXXXXll	unsigned ll	= pero para long long's.

## 2. Estructuras

### 2.1. RMQ (static)

Dado un arreglo y una operación asociativa *idempotente*, `get(i, j)` opera sobre el rango `[i, j]`. Restricción:  $LVL \geq \text{ceil}(\log n)$ ; Usar `[]` para llenar arreglo y luego `build()`.

```

1 struct RMQ{
2     #define LVL 10
3     tipo vec[LVL][1<<(LVL+1)];
4     tipo &operator[] (int p){return vec[0][p];}
5     tipo get(int i, int j) { //intervalo [i,j]
6         int p = 31-__builtin_clz(j-i);
7         return min(vec[p][i], vec[p][j-(1<<p)]);
8     }
9     void build(int n) { //O(nlogn)
10        int mp = 31-__builtin_clz(n);
11        forn(p, mp) forn(x, n-(1<<p))
12            vec[p+1][x] = min(vec[p][x], vec[p][x+(1<<p)]);
13    }
14 };

```

### 2.2. RMQ (dynamic)

```

1 //Dado un arreglo y una operacion asociativa con neutro, get(i, j) opera
   sobre el rango [i, j].
2 #define MAXN 100000
3 #define operacion(x, y) max(x, y)
4 const int neutro=0;
5 struct RMQ{
6     int sz;
7     tipo t[4*MAXN];
8     tipo &operator[] (int p){return t[sz+p];}
9     void init(int n){ //O(nlgn)
10        sz = 1 << (32-__builtin_clz(n));
11        forr(i, sz, 2*sz) t[i]=neutro;
12    }
13    void updall(){ //O(n)
14        dforn(i, sz) t[i]=operacion(t[2*i], t[2*i+1]);}
15    tipo get(int i, int j){return get(i,j,1,0,sz);}
16    tipo get(int i, int j, int n, int a, int b){ //O(lgn)
17        if(j<=a || i>=b) return neutro;
18        if(i<=a && b<=j) return t[n];

```

```

19        int c=(a+b)/2;
20        return operacion(get(i, j, 2*n, a, c), get(i, j, 2*n+1, c, b));
21    }
22    void set(int p, tipo val){ //O(lgn)
23        for(p+=sz; p>0 && t[p]!=val;){
24            t[p]=val;
25            p/=2;
26            val=operacion(t[p*2], t[p*2+1]);
27        }
28    }
29 }rmq;
30 //Usage:
31 cin >> n; rmq.init(n); forn(i, n) cin >> rmq[i]; rmq.updall();

```

### 2.3. RMQ (lazy)

```

1 //Dado un arreglo y una operacion asociativa con neutro, get(i, j) opera
   sobre el rango [i, j].
2 typedef int Elem; //Elem de los elementos del arreglo
3 typedef int Alt; //Elem de la alteracion
4 #define operacion(x,y) x+y
5 const Elem neutro=0; const Alt neutro2=0;
6 #define MAXN 100000
7 struct RMQ{
8     int sz;
9     Elem t[4*MAXN];
10    Alt dirty[4*MAXN]; //las alteraciones pueden ser de distinto Elem
11    Elem &operator[] (int p){return t[sz+p];}
12    void init(int n){ //O(nlgn)
13        sz = 1 << (32-__builtin_clz(n));
14        forr(i, sz, 2*sz) t[i]=neutro;
15        forn(i, 2*sz) dirty[i]=neutro2;
16    }
17    void push(int n, int a, int b){ //propaga el dirty a sus hijos
18        if(dirty[n]!=0){
19            t[n]+=dirty[n]*(b-a); //altera el nodo
20            if(n<sz){
21                dirty[2*n]+=dirty[n];
22                dirty[2*n+1]+=dirty[n];
23            }
24            dirty[n]=0;
25        }
26    }

```

```

27 Elem get(int i, int j, int n, int a, int b){//0(lgn)
28     if(j<=a || i>=b) return neutro;
29     push(n, a, b);//corrige el valor antes de usarlo
30     if(i<=a && b<=j) return t[n];
31     int c=(a+b)/2;
32     return operacion(get(i, j, 2*n, a, c), get(i, j, 2*n+1, c, b));
33 }
34 Elem get(int i, int j){return get(i,j,1,0,sz);}
35 //altera los valores en [i, j) con una alteracion de val
36 void alterar(Alt val, int i, int j, int n, int a, int b){//0(lgn)
37     push(n, a, b);
38     if(j<=a || i>=b) return;
39     if(i<=a && b<=j){
40         dirty[n]+=val;
41         push(n, a, b);
42         return;
43     }
44     int c=(a+b)/2;
45     alterar(val, i, j, 2*n, a, c), alterar(val, i, j, 2*n+1, c, b);
46     t[n]=operacion(t[2*n], t[2*n+1]);//por esto es el push de arriba
47 }
48 void alterar(Alt val, int i, int j){alterar(val,i,j,1,0,sz);}
49 }rmq;

```

## 2.4. Fenwick Tree

```

1 //For 2D threat each column as a Fenwick tree, by adding a nested for in
  each operation
2 struct Fenwick{
3     static const int sz=1000001;
4     tipo t[sz];
5     void adjust(int p, tipo v){//valid with p in [1, sz), 0(lgn)
6         for(; p<sz; p+=(p&-p)) t[p]+=v; }
7     tipo sum(int p){//cumulative sum in [1, p], 0(lgn)
8         tipo s=0;
9         for(; p; p--(p&-p)) s+=t[p];
10        return s;
11    }
12    tipo sum(int a, int b){return sum(b)-sum(a-1);}
13    //get largest value with cumulative sum less than or equal to x;
14    //for smallest, pass x-1 and add 1 to result
15    int getind(tipo x) {//0(lgn)
16        int idx = 0, mask = N;

```

```

17        while(mask && idx < N) {
18            int t = idx + mask;
19            if(x >= tree[t])
20                idx = t, x -= tree[t];
21            mask >>= 1;
22        }
23        return idx;
24    }
25 };

```

## 2.5. Union Find

```

1 struct UnionFind{
2     vector<int> f;//the array contains the parent of each node
3     void init(int n){f.clear(); f.insert(f.begin(), n, -1);}
4     int comp(int x){return (f[x]==-1?x:f[x]=comp(f[x]));} //0(1)
5     bool join(int i, int j) {
6         bool con=comp(i)==comp(j);
7         if(!con) f[comp(i)] = comp(j);
8         return con;
9     }
10 };

```

## 2.6. Disjoint Intervals

```

1 bool operator< (const ii &a, const ii &b) {return a.fst<b.fst;}
2 //Stores intervals as [first, second]
3 //in case of a collision it joins them in a single interval
4 struct disjoint_intervals {
5     set<ii> segs;
6     void insert(ii v) {//0(lgn)
7         if(v.snd-v.fst==0.) return;//0J0
8         set<ii>::iterator it,at;
9         at = it = segs.lower_bound(v);
10        if (at!=segs.begin() && (--at)->snd >= v.fst)
11            v.fst = at->fst, --it;
12        for(; it!=segs.end() && it->fst <= v.snd; segs.erase(it++))
13            v.snd=max(v.snd, it->snd);
14        segs.insert(v);
15    }
16 };

```

## 2.7. RMQ (2D)

```

1 struct RMQ2D{
2     static const int sz=1024;
3     RMQ t[sz];
4     RMQ &operator[] (int p){return t[sz/2+p];}
5     void build(int n, int m){//O(nm)
6         forr(y, sz/2, sz/2+m)
7             t[y].build(m);
8         forr(y, sz/2+m, sz)
9             forn(x, sz)
10                t[y].t[x]=0;
11         dforr(y, sz/2)
12             forn(x, sz)
13                t[y].t[x]=max(t[y*2].t[x], t[y*2+1].t[x]);
14     }
15     void set(int x, int y, tipo v){//O(lgm.lgn)
16         y+=sz/2;
17         t[y].set(x, v);
18         while(y/=2)
19             t[y].set(x, max(t[y*2].t[x], t[y*2+1].t[x]));
20     }
21     //O(lgm.lgn)
22     int get(int x1, int y1, int x2, int y2, int n=1, int a=0, int b=sz/2){
23         if(y2<=a || y1>=b) return 0;
24         if(y1<=a && b<=y2) return t[n].get(x1, x2);
25         int c=(a+b)/2;
26         return max(get(x1, y1, x2, y2, 2*n, a, c),
27                    get(x1, y1, x2, y2, 2*n+1, c, b));
28     }
29 };
30 //Example to initialize a grid of M rows and N columns:
31 RMQ2D rmq;
32 forn(i, M)
33     forn(j, N)
34         cin >> rmq[i][j];
35 rmq.build(N, M);

```

## 2.8. Big Int

```

1 #define BASEXP 6
2 #define BASE 1000000
3 #define LMAX 1000
4 struct bint{
5     int l;

```

```

6     ll n[LMAX];
7     bint(ll x=0){
8         l=0;
9         forn(i, LMAX){
10             n[i]=x%BASE;
11             x/=BASE;
12             l+=!!x||!i;
13         }
14     }
15     bint(string x){
16         l=(x.size()-1)/BASEXP+1;
17         fill(n, n+LMAX, 0);
18         ll r=1;
19         forn(i, sz(x)){
20             n[i / BASEXP] += r * (x[x.size()-1-i]-'0');
21             r*=10; if(r==BASE)r=1;
22         }
23     }
24     void out(){
25         cout << n[l-1];
26         dforr(i, l-1) printf("%6.6llu", n[i]);//6=BASEXP!
27     }
28     void invar(){
29         fill(n+1, n+LMAX, 0);
30         while(l>1 && !n[l-1]) l--;
31     }
32 };
33 bint operator+(const bint&a, const bint&b){
34     bint c;
35     c.l = max(a.l, b.l);
36     ll q = 0;
37     forn(i, c.l) q += a.n[i]+b.n[i], c.n[i]=q %BASE, q/=BASE;
38     if(q) c.n[c.l++] = q;
39     c.invar();
40     return c;
41 }
42 pair<bint, bool> lresta(const bint& a, const bint& b) // c = a - b
43 {
44     bint c;
45     c.l = max(a.l, b.l);
46     ll q = 0;
47     forn(i, c.l) q += a.n[i]-b.n[i], c.n[i]=(q+BASE) %BASE, q=(q+BASE)/
        BASE-1;

```

```

48     c.invar();
49     return make_pair(c, !q);
50 }
51 bint& operator-= (bint& a, const bint& b){return a=lresta(a, b).first;}
52 bint operator- (const bint&a, const bint&b){return lresta(a, b).first;}
53 bool operator< (const bint&a, const bint&b){return !lresta(a, b).second;}
54 bool operator<= (const bint&a, const bint&b){return lresta(b, a).second;}
55 bool operator==(const bint&a, const bint&b){return a <= b && b <= a;}
56 bint operator*(const bint&a, ll b){
57     bint c;
58     ll q = 0;
59     forn(i, a.l) q += a.n[i]*b, c.n[i] = q %BASE, q/=BASE;
60     c.l = a.l;
61     while(q) c.n[c.l++] = q %BASE, q/=BASE;
62     c.invar();
63     return c;
64 }
65 bint operator*(const bint&a, const bint&b){
66     bint c;
67     c.l = a.l+b.l;
68     fill(c.n, c.n+b.l, 0);
69     forn(i, a.l){
70         ll q = 0;
71         forn(j, b.l) q += a.n[i]*b.n[j]+c.n[i+j], c.n[i+j] = q %BASE, q
            /=BASE;
72         c.n[i+b.l] = q;
73     }
74     c.invar();
75     return c;
76 }
77 pair<bint, ll> ldiv(const bint& a, ll b){// c = a / b ; rm = a % b
78     bint c;
79     ll rm = 0;
80     dforn(i, a.l){
81         rm = rm * BASE + a.n[i];
82         c.n[i] = rm / b;
83         rm %= b;
84     }
85     c.l = a.l;
86     c.invar();
87     return make_pair(c, rm);

```

```

88 }
89 bint operator/(const bint&a, ll b){return ldiv(a, b).first;}
90 ll operator%(const bint&a, ll b){return ldiv(a, b).second;}
91 pair<bint, bint> ldiv(const bint& a, const bint& b){
92     bint c;
93     bint rm = 0;
94     dforn(i, a.l){
95         if (rm.l==1 && !rm.n[0])
96             rm.n[0] = a.n[i];
97         else{
98             dforn(j, rm.l) rm.n[j+1] = rm.n[j];
99             rm.n[0] = a.n[i];
100            rm.l++;
101        }
102        ll q = rm.n[b.l] * BASE + rm.n[b.l-1];
103        ll u = q / (b.n[b.l-1] + 1);
104        ll v = q / b.n[b.l-1] + 1;
105        while (u < v-1){
106            ll m = (u+v)/2;
107            if (b*m <= rm) u = m;
108            else v = m;
109        }
110        c.n[i]=u;
111        rm-=b*u;
112    }
113    c.l=a.l;
114    c.invar();
115    return make_pair(c, rm);
116 }
117 bint operator/(const bint&a, const bint&b){return ldiv(a, b).first;}
118 bint operator%(const bint&a, const bint&b){return ldiv(a, b).second;}

```

## 2.9. Modnum

```

1 struct mnum{
2     static const tipo mod=12582917;
3     tipo v;
4     mnum(tipo v=0): v(v%mod) {}
5     mnum operator+(mnum b){return v+b.v;}
6     mnum operator-(mnum b){return v>=b.v? v-b.v : mod-b.v+v;}
7     mnum operator*(mnum b){return v*b.v;}
8     mnum operator^(int n){
9         if(!n) return 1;

```

```

10     return n%2? (*this)^(n/2)*(*this) : (*this)^(n/2);}
11 };

```

## 2.10. Treap

```

1  typedef int Key;
2
3  typedef struct node *pnode;
4  struct node{
5      Key key;
6      int prior, size;
7      pnode l,r;
8      node(Key key=0, int prior=0): key(key), prior(prior), size(1), l(0),
          r(0) {}
9  };
10 struct treap {
11     pnode root;
12     treap(): root(0) {}
13     int size(pnode p) { return p ? p->size : 0; }
14     int size() { return size(root); }
15     void push(pnode p) {
16         // modificar y propagar el dirty a los hijos aca(para lazy)
17     }
18     // Update function and size from children's values
19     void pull(pnode p) { //recalcular valor del nodo aca (para rmq)
20         p->size = 1 + size(p->l) + size(p->r);
21     }
22     pnode merge(pnode l, pnode r) {
23         if (!l || !r) return l ? l : r;
24         push(l), push(r);
25         pnode t;
26         if (l->prior < r->prior) l->r=merge(l->r, r), t = l;
27         else r->l=merge(l, r->l), t = r;
28         pull(t);
29         return t;
30     } //opcional:
31     void merge(treap t) {root = merge(root, t.root), t.root=0;}
32     //*****KEY OPERATIONS*****//
33     void splitKey(pnode t, Key key, pnode &l, pnode &r) {
34         if (!t) return void(l = r = 0);
35         push(t);
36         if (key <= t->key) splitKey(t->l, key, l, t->l), r = t;
37         else splitKey(t->r, key, t->r, r), l = t;

```

```

38         pull(t);
39     }
40     void insertKey(Key key) {
41         pnode elem = new node(key, rand());
42         pnode t1, t2; splitKey(root, key, t1, t2);
43         t1=merge(t1,elem);
44         root=merge(t1,t2);
45     }
46     void eraseKeys(Key key1, Key key2) {
47         pnode t1,t2,t3;
48         splitKey(root,key1,t1,t2);
49         splitKey(t2,key2, t2, t3);
50         root=merge(t1,t3);
51     }
52     void eraseKey(pnode &t, Key key) {
53         if (!t) return;
54         push(t);
55         if (key == t->key) t=merge(t->l, t->r);
56         else if (key < t->key) eraseKey(t->l, key);
57         else eraseKey(t->r, key);
58         pull(t);
59     }
60     void eraseKey(Key key) {eraseKey(root, key);}
61     pnode findKey(pnode t, Key key) {
62         if (!t) return 0;
63         if (key == t->key) return t;
64         if (key < t->key) return findKey(t->l, key);
65         return findKey(t->r, key);
66     }
67     pnode findKey(Key key) { return findKey(root, key); }
68     //*****POS OPERATIONS*****// No mezclar con las funciones Key
69     //(No funciona con pos:)
70     void splitSize(pnode t, int sz, pnode &l, pnode &r) {
71         if (!t) return void(l = r = 0);
72         push(t);
73         if (sz <= size(t->l)) splitSize(t->l, sz, l, t->l), r = t;
74         else splitSize(t->r, sz - 1 - size(t->l), t->r, r), l = t;
75         pull(t);
76     }
77     void insertPos(int pos, Key key) {
78         pnode elem = new node(key, rand());
79         pnode t1,t2; splitSize(root, pos, t1, t2);
80         t1=merge(t1,elem);

```

```

81     root=merge(t1,t2);
82 }
83 void erasePos(int pos1, int pos2=-1) {
84     if(pos2==-1) pos2=pos1+1;
85     pnode t1,t2,t3;
86     splitSize(root,pos1,t1,t2);
87     splitSize(t2,pos2-pos1,t2,t3);
88     root=merge(t1, t2);
89 }
90 pnode findPos(pnode t, int pos) {
91     if(!t) return 0;
92     if(pos <= size(t->l)) return findPos(t->l, pos);
93     return findPos(t->r, pos - 1 - size(t->l));
94 }
95 Key &operator[](int pos){return findPos(root, pos)->key;}//ojito
96 };

```

### 2.11. Gain-Cost Set

```

1 //esta estructura mantiene pairs(beneficio, costo)
2 //de tal manera que en el set quedan ordenados
3 //por beneficio Y COSTO creciente. (va borrando los que no son optimos)
4 struct V{
5     int gain, cost;
6     bool operator<(const V &b)const{return gain<b.gain;}
7 };
8 set<V> s;
9 void add(V x){
10     set<V>::iterator p=s.lower_bound(x);//primer elemento mayor o igual
11     if(p!=s.end() && p->cost <= x.cost) return;//ya hay uno mejor
12     p=s.upper_bound(x);//primer elemento mayor
13     if(p!=s.begin()){//borro todos los peores (<=beneficio y >=costo)
14         --p;//ahora es ultimo elemento menor o igual
15         while(p->cost >= x.cost){
16             if(p==s.begin()){s.erase(p); break;}
17             s.erase(p--);
18         }
19     }
20     s.insert(x);
21 }
22 int get(int gain){//minimo costo de obtener tal ganancia
23     set<V>::iterator p=s.lower_bound((V){gain, 0});
24     return p==s.end()? INF : p->cost;}

```

## 3. Algos

### 3.1. Longest Increasing Subsequence

```

1 //Para non-increasing, cambiar comparaciones y revisar busq binaria
2 //Given an array, paint it in the least number of colors so that each
   color turns to a non-increasing subsequence.
3 //Solution:Min number of colors=Length of the longest increasing
   subsequence
4 int N, a[MAXN];//secuencia y su longitud
5 ii d[MAXN+1];//d[i]=ultimo valor de la subsecuencia de tamaño i
6 int p[MAXN];//padres
7 vector<int> R;//respuesta
8 void rec(int i){
9     if(i==-1) return;
10    R.push_back(a[i]);
11    rec(p[i]);
12 }
13 int lis(){//O(nlogn)
14     d[0] = ii(-INF, -1); forn(i, N) d[i+1]=ii(INF, -1);
15     forn(i, N){
16         int j = upper_bound(d, d+N+1, ii(a[i], INF))-d;
17         if (d[j-1].first < a[i]&&a[i] < d[j].first){
18             p[i]=d[j-1].second;
19             d[j] = ii(a[i], i);
20         }
21     }
22     R.clear();
23     dforn(i, N+1) if(d[i].first!=INF){
24         rec(d[i].second);//reconstruir
25         reverse(R.begin(), R.end());
26         return i;//longitud
27     }
28     return 0;
29 }

```

### 3.2. Manacher

```

1 int d1[MAXN];//d1[i]=long del maximo palindromo impar con centro en i
2 int d2[MAXN];//d2[i]=analogo pero para longitud par
3 //0 1 2 3 4
4 //a a b c c <--d1[2]=3
5 //a a b b <--d2[2]=2 (estan uno antes)

```



```

6 void manacher(){
7     int l=0, r=-1, n=sz(s);
8     forn(i, n){
9         int k=(i>r? 1 : min(d1[l+r-i], r-i));
10        while(i+k<n && i-k>=0 && s[i+k]==s[i-k]) ++k;
11        d1[i] = k--;
12        if(i+k > r) l=i-k, r=i+k;
13    }
14    l=0, r=-1;
15    forn(i, n){
16        int k=(i>r? 0 : min(d2[l+r-i+1], r-i+1))+1;
17        while(i+k-1<n && i-k>=0 && s[i+k-1]==s[i-k]) k++;
18        d2[i] = --k;
19        if(i+k-1 > r) l=i-k, r=i+k-1;
20    }

```

## 4. Strings

### 4.1. KMP

```

1 string T;//cadena donde buscar(what)
2 string P;//cadena a buscar(what)
3 int b[MAXLEN]; //back table
4 void kmppre(){//by gabina with love
5     int i =0, j=-1; b[0]=-1;
6     while(i<sz(P)){
7         while(j>=0 && P[i] != P[j]) j=b[j];
8         i++, j++;
9         b[i] = j;
10    }
11 }
12
13 void kmp(){
14     int i=0, j=0;
15     while(i<sz(T)){
16         while(j>=0 && T[i]!=P[j]) j=b[j];
17         i++, j++;
18         if(j==sz(P)){
19             printf("P is found at index %d in T\n", i-j);
20             j=b[j];
21         }
22     }
23 }

```

### 4.2. Trie

```

1 struct trie{
2     map<char, trie> m;
3     void add(const string &s, int p=0){
4         if(s[p]) m[s[p]].add(s, p+1);
5     }
6     void dfs(){
7         //Do stuff
8         forall(it, m)
9             it->second.dfs();
10    }
11 };

```

### 4.3. Suffix Array (corto, nlog2n)

```

1 pair<int, int> sf[MAXN];
2 bool comp(int lhs, int rhs) {return sf[lhs] < sf[rhs];}
3 struct SuffixArray {
4     //sa guarda los indices de los sufijos ordenados
5     int sa[MAXN], r[MAXN];
6     void init(const char *a, int n) {
7         forn(i, n) r[i] = a[i];
8         for(int m = 1; m < n; m <= 1) {
9             forn(i, n) sa[i]=i, sf[i] = make_pair(r[i], i+m<n? r[i+m]:-1);
10            stable_sort(sa, sa+n, comp);
11            r[sa[0]] = 0;
12            forr(i, 1, n) r[sa[i]]= sf[sa[i]] != sf[sa[i] - 1] ? i : r[sa[i-1]];
13        }
14    }
15 } sa;

```

### 4.4. Suffix Array (largo, nlogn)

```

1 #define MAX_N 1000
2 #define rBOUND(x) (x<n? r[x] : 0)
3 //sa will hold the suffixes in order.
4 int sa[MAX_N], r[MAX_N], n;
5 string s; //input string, n=sz(s)
6
7 void countingSort(int k){
8     int f[MAX_N], tmpsa[MAX_N];
9     zero(f);

```

```

10  forn(i, n) f[rBOUND(i+k)]++;
11  int sum=0;
12  forn(i, max(255, n)){
13      int t=f[i]; f[i]=sum; sum+=t;}
14  forn(i, n)
15      tmpsa[f[rBOUND(sa[i]+k)]]+=sa[i];
16  memcpy(sa, tmpsa, sizeof(sa));
17  }
18  void constructsa(){//O(n log n)
19      n=sz(s);
20      forn(i, n) sa[i]=i, r[i]=s[i];
21      for(int k=1; k<n; k<=1){
22          countingSort(k), countingSort(0);
23          int rank, tmpr[MAX_N];
24          tmpr[sa[0]]=rank=0;
25          forr(i, 1, n)
26              tmpr[sa[i]]=(r[sa[i]]==r[sa[i-1]] && r[sa[i]+k]==r[sa[i-1]+k])?
                  rank : ++rank;
27          memcpy(r, tmpr, sizeof(r));
28          if(r[sa[n-1]]==n-1) break;
29      }
30  }
31  void print(){//for debug
32      forn(i, n)
33          cout << i << '␣' <<
34          s.substr(sa[i], s.find( '$', sa[i])-sa[i]) << endl;}

```

#### 4.5. String Matching With Suffix Array

```

1  //returns (lowerbound, upperbound) of the search
2  ii stringMatching(string P){ //O(sz(P)lgn)
3      int lo=0, hi=n-1, mid=lo;
4      while(lo<hi){
5          mid=(lo+hi)/2;
6          int res=s.compare(sa[mid], sz(P), P);
7          if(res>=0) hi=mid;
8          else lo=mid+1;
9      }
10     if(s.compare(sa[lo], sz(P), P)!=0) return ii(-1, -1);
11     ii ans; ans.fst=lo;
12     lo=0, hi=n-1, mid;
13     while(lo<hi){
14         mid=(lo+hi)/2;

```

```

15     int res=s.compare(sa[mid], sz(P), P);
16     if(res>0) hi=mid;
17     else lo=mid+1;
18 }
19 if(s.compare(sa[hi], sz(P), P)!=0) hi--;
20 ans.snd=hi;
21 return ans;
22 }

```

#### 4.6. LCP (Longest Common Prefix)

```

1  //Calculates the LCP between consecutives suffixes in the Suffix Array.
2  //LCP[i] is the length of the LCP between sa[i] and sa[i-1]
3  int LCP[MAX_N], phi[MAX_N], PLCP[MAX_N];
4  void computeLCP(){//O(n)
5      phi[sa[0]]=-1;
6      forr(i, 1, n) phi[sa[i]]=sa[i-1];
7      int L=0;
8      forn(i, n){
9          if(phi[i]==-1) {PLCP[i]=0; continue;}
10         while(s[i+L]==s[phi[i]+L]) L++;
11         PLCP[i]=L;
12         L=max(L-1, 0);
13     }
14     forn(i, n) LCP[i]=PLCP[sa[i]];
15 }

```

#### 4.7. Corasick

```

1
2  struct trie{
3      map<char, trie> next;
4      trie* tran[256]; //transiciones del automata
5      int idhoja, szhoja; //id de la hoja o 0 si no lo es
6      //link lleva al sufijo mas largo, nxthoja lleva al mas largo pero que
        es hoja
7      trie *padre, *link, *nxthoja;
8      char pch; //caracter que conecta con padre
9      trie(): tran(), idhoja(), padre(), link() {}
10     void insert(const string &s, int id=1, int p=0){ //id>0!!!
11         if(p<sz(s)){
12             trie &ch=next[s[p]];
13             tran[(int)s[p]]=&ch;
14             ch.padre=this, ch.pch=s[p];

```

```

15     ch.insert(s, id, p+1);
16 }
17 else idhoja=id, szhoja=sz(s);
18 }
19 trie* get_link() {
20     if(!link){
21         if(!padre) link=this;//es la raiz
22         else if(!padre->padre) link=padre;//hijo de la raiz
23         else link=padre->get_link()->get_tran(pch);
24     }
25     return link;
26 }
27 trie* get_tran(int c) {
28     if(!tran[c])
29         tran[c] = !padre? this : this->get_link()->get_tran(c);
30     return tran[c];
31 }
32 trie *get_nxthoja(){
33     if(!nxthoja) nxthoja = get_link()->idhoja? link : link->nxthoja;
34     return nxthoja;
35 }
36 void print(int p){
37     if(idhoja)
38         cout << "found_" << idhoja << "_at_position_" << p-szhoja << endl
39         ;
40     if(get_nxthoja()) get_nxthoja()->print(p);
41 }
42 void matching(const string &s, int p=0){
43     print(p);
44     if(p<sz(s)) get_tran(s[p])->matching(s, p+1);

```

## 5. Geometría

#define EPS 1e-9

### 5.1. Punto

```

1 struct pto{
2     tipo x, y;
3     pto(tipo x=0, tipo y=0):x(x),y(y){}
4     pto operator+(pto a){return pto(x+a.x, y+a.y);}
5     pto operator-(pto a){return pto(x-a.x, y-a.y);}
6     pto operator+(tipo a){return pto(x+a, y+a);}

```

```

7     pto operator*(tipo a){return pto(x*a, y*a);}
8     pto operator/(tipo a){return pto(x/a, y/a);}
9     //dot product, producto interno:
10    tipo operator*(pto a){return x*a.x+y*a.y;}
11    //module of the cross product or vectorial product:
12    //if a is less than 180 clockwise from b, a^b>0
13    tipo operator^(pto a){return x*a.y-y*a.x;}
14    //returns true if this is at the left side of line qr
15    bool left(pto q, pto r){return ((q-*this)^(r-*this))>0;}
16    bool operator<(const pto &a) const{return x<a.x || (abs(x-a.x)<EPS &&
17        y<a.y);}
18    bool operator==(pto a){return abs(x-a.x)<EPS && abs(y-a.y)<EPS;}
19    double norm(){return sqrt(x*x+y*y);}
20    tipo norm_sq(){return x*x+y*y;}
21 };
22 double dist(pto a, pto b){return (b-a).norm();}
23 typedef pto vec;
24 double angle(pto a, pto o, pto b){
25     vec oa=a-o, ob=b-o;
26     return acos((oa*ob) / sqrt(oa.norm_sq()*ob.norm_sq()));}
27
28 //rotate p by theta rads CCW w.r.t. origin (0,0)
29 pto rotate(pto p, double theta){
30     return pto(p.x*cos(theta)-p.y*sin(theta),
31         p.x*sin(theta)+p.y*cos(theta));
32 }

```

### 5.2. Line

```

1 struct line{
2     line() {}
3     double a,b,c;//Ax+By=C
4     //pto MUST store float coordinates!
5     line(double a, double b, double c):a(a),b(b),c(c){}
6     line(pto p, pto q): a(q.y-p.y), b(p.x-q.x), c(a*p.x+b*p.y) {}
7 };
8 bool parallels(line l1, line l2){return abs(l1.a*l2.b-l2.a*l1.b)<EPS;}
9 pto inter(line l1, line l2){//intersection
10     double det=l1.a*l2.b-l2.a*l1.b;
11     if(abs(det)<EPS) return pto(INF, INF);//parallels
12     return pto(l2.b*l1.c-l1.b*l2.c, l1.a*l2.c-l2.a*l1.c)/det;
13 }

```

### 5.3. Segment

```

1 struct segm{
2   pto s,f;
3   segm(pto s, pto f):s(s), f(f) {}
4   pto closest(pto p) {//use for dist to point
5     double l2 = dist_sq(s, f);
6     if(l2==0.) return s;
7     double t = ((p-s)*(f-s))/l2;
8     if (t<0.) return s;//not write if is a line
9     else if(t>1.)return f;//not write if is a line
10    return s+((f-s)*t);
11  }
12  bool inside(pto p){
13  return ((s-p)^(f-p))==0 && min(s, f)<*this&&*this<max(s, f);}
14 };
15
16 bool insidebox(pto a, pto b, pto p) {
17   return (a.x-p.x)*(p.x-b.x)>-EPS && (a.y-p.y)*(p.y-b.y)>-EPS;
18 }
19 pto inter(segm s1, segm s2){
20   pto r=inter(line(s1.s, s1.f), line(s2.s, s2.f));
21   if(insidebox(s1.s,s1.f,p) && insidebox(s2.s,s2.f,p))
22     return r;
23   return pto(INF, INF);
24 }

```

### 5.4. Rectangle

```

1 struct rect{
2   //lower-left and upper-right corners
3   pto lw, up;
4 };
5 //returns if there's an intersection and stores it in r
6 bool inter(rect a, rect b, rect &r){
7   r.lw=pto(max(a.lw.x, b.lw.x), max(a.lw.y, b.lw.y));
8   r.up=pto(min(a.up.x, b.up.x), min(a.up.y, b.up.y));
9   //check case when only a edge is common
10  return r.lw.x<r.up.x && r.lw.y<r.up.y;
11 }

```

### 5.5. Polygon Area

```

1 double area(vector<tipo> &p){//0(sz(p))

```

```

2   double area=0;
3   forn(i, sz(p)) area+=p[i]^p[(i+1)%sz(p)];
4   //if points are in clockwise order then area is negative
5   return abs(area)/2;
6 }
7 //Area ellipse = M_PI*a*b where a and b are the semi axis lengths
8 //Area triangle = sqrt(s*(s-a)(s-b)(s-c)) where s=(a+b+c)/2

```

### 5.6. Circle

```

1 vec perp(vec v){return vec(-v.y, v.x);}
2 line bisector(pto x, pto y){
3   line l=line(x, y); pto m=(x+y)/2;
4   return line(-l.b, l.a, -l.b*m.x+l.a*m.y);
5 }
6 struct Circle{
7   pto o;
8   double r;
9   //circle determined by three points, uses line
10  Circle(pto x, pto y, pto z){
11    o=inter(bisector(x, y), bisector(y, z));
12    r=dist(o, x);
13  }
14  pair<pto, pto> ptosTang(pto p){
15    pto m=(p+o)/2;
16    tipo d=dist(o, m);
17    tipo a=r*r/(2*d);
18    tipo h=sqrt(r*r-a*a);
19    pto m2=o+(m-o)*a/d;
20    vec per=perp(m-o)/d;
21    return mkp(m2-per*h, m2+per*h);
22  }
23 };
24 //finds the center of the circle containing p1 and p2 with radius r
25 //as there may be two solutions swap p1, p2 to get the other
26 bool circle2PtsRad(pto p1, pto p2, double r, pto &c){
27   double d2=(p1-p2).norm_sq(), det=r*r/d2-0.25;
28   if(det<0) return false;
29   c=(p1+p2)/2+perp(p2-p1)*sqrt(det);
30   return true;
31 }

```

### 5.7. Point in Poly

```

1 //checks if v is inside of P, using ray casting
2 //works with convex and concave.
3 //excludes boundaries, handle it separately using segment.inside()
4 bool inPolygon(pto v, vector<pto>& P) {
5     bool c = false;
6     forn(i, sz(P)){
7         int j=(i+1)%sz(P);
8         if((P[j].y>v.y) != (P[i].y > v.y) &&
9         (v.x < (P[i].x - P[j].x) * (v.y-P[j].y) / (P[i].y - P[j].y) + P[j].x))
10             c = !c;
11     }
12     return c;
13 }

```

### 5.8. Convex Check CHECK

```

1 bool isConvex(vector<int> &p){//O(N)
2     int N=sz(p);
3     if(N<3) return false;
4     bool isLeft=p[0].left(p[1], p[2]);
5     forr(i, 1, N)
6         if(p[i].left(p[(i+1)%N], p[(i+2)%N])!=isLeft)
7             return false;
8     return true; }

```

### 5.9. Convex Hull

```

1 //stores convex hull of P in S, CCW order
2 void CH(vector<pto>& P, vector<pto> &S){
3     S.clear();
4     sort(P.begin(), P.end());
5     forn(i, sz(P)){
6         while(sz(S)>= 2 && S[sz(S)-1].left(S[sz(S)-2], P[i])) S.pop_back();
7         S.pb(P[i]);
8     }
9     S.pop_back();
10    int k=sz(S);
11    dforn(i, sz(P)){
12        while(sz(S) >= k+2 && S[sz(S)-1].left(S[sz(S)-2], P[i])) S.pop_back
13            ();
14        S.pb(P[i]);
15    }
16    S.pop_back();
17 }

```

### 5.10. Cut Polygon

```

1 //cuts polygon Q along the line ab
2 //stores the left side (swap a, b for the right one) in P
3 void cutPolygon(pto a, pto b, vector<pto> Q, vector<pto> &P){
4     P.clear();
5     forn(i, sz(Q)){
6         double left1=(b-a)^(Q[i]-a), left2=(b-a)^(Q[(i+1)%sz(Q)]-a);
7         if(left1>=0) P.pb(Q[i]);
8         if(left1*left2<0)
9             P.pb(inter(line(Q[i], Q[(i+1)%sz(Q)]), line(a, b)));
10    }
11 }

```

### 5.11. Bresenham

```

1 //plot a line approximation in a 2d map
2 void bresenham(pto a, pto b){
3     pto d=b-a; d.x=abs(d.x), d.y=abs(d.y);
4     pto s(a.x<b.x? 1: -1, a.y<b.y? 1: -1);
5     int err=d.x-d.y;
6     while(1){
7         m[a.x][a.y]=1;//plot
8         if(a==b) break;
9         int e2=2*err;
10        if(e2 > -d.y){
11            err-=d.y, a.x+=s.x;
12        }
13        if(e2 < d.x){
14            err+= d.x, a.y+= s.y;
15        }
16    }
17 }

```

### 5.12. Rotate Matrix

```

1 //rotates matrix t 90 degrees clockwise
2 //using auxiliary matrix t2(faster)
3 void rotate(){
4     forn(x, n) forn(y, n)
5         t2[n-y-1][x]=t[x][y];
6     memcpy(t, t2, sizeof(t));
7 }

```

## 6. Math

### 6.1. Identidades

$$\sum_{i=0}^n \binom{n}{i} = 2^n$$

$$\sum_{i=0}^n i \binom{n}{i} = n * 2^{n-1}$$

$$\sum_{i=m}^n i = \frac{n(n+1)}{2} - \frac{m(m-1)}{2} = \frac{(n+1-m)(n+m)}{2}$$

$$\sum_{i=0}^n i = \sum_{i=1}^n i = \frac{n(n+1)}{2}$$

$$\sum_{i=0}^n i^2 = \frac{n(n+1)(2n+1)}{6} = \frac{n^3}{3} + \frac{n^2}{2} + \frac{n}{6}$$

$$\sum_{i=0}^n i(i-1) = \frac{8}{6} \left(\frac{n}{2}\right) \left(\frac{n}{2} + 1\right) (n+1)$$

(doubles) → Sino ver caso impar y par

$$\sum_{i=0}^n i^3 = \left(\frac{n(n+1)}{2}\right)^2 = \frac{n^4}{4} + \frac{n^3}{2} + \frac{n^2}{4} = \left[\sum_{i=1}^n i\right]^2$$

$$\sum_{i=0}^n i^4 = \frac{n(n+1)(2n+1)(3n^2+3n-1)}{30} = \frac{n^5}{5} + \frac{n^4}{2} + \frac{n^3}{3} - \frac{n}{30}$$

$$\sum_{i=0}^n i^p = \frac{(n+1)^{p+1}}{p+1} + \sum_{k=1}^p \frac{B_k}{p-k+1} \binom{p}{k} (n+1)^{p-k+1}$$

### 6.2. Combinatorio

```

1 | forn(i, MAXN+1){ //comb[i][k]=i tomados de a k
2 |   comb[i][0]=comb[i][i]=1;
3 |   forr(k, 1, i) comb[i][k]=(comb[i-1][k]+comb[i-1][k-1])%MOD;
4 | }
5 |
6 | ll lucas (ll n, ll k, int p){ //Calcula (n,k)%p teniendo comb[p][p]
   |   precalculado.
7 |   ll aux = 1;
8 |   while (n + k){

```

```

9 |   aux = (aux * comb[n%p][k%p]) %p;
10 |   n/=p, k/=p;
11 | }
12 | return aux;
13 | }

```

### 6.3. Exp. de Numeros Mod.

```

1 | ll expmod (ll b, ll e, ll m){ //O(log b)
2 |   if(!e) return 1;
3 |   ll q= expmod(b,e/2,m); q=(q*q)%m;
4 |   return e%2? (b * q)%m : q;
5 | }

```

### 6.4. Exp. de Matrices y Fibonacci en log(n)

```

1 | struct M22{ // la b|
2 |   tipo a,b,c,d; // lc dl
3 |   M22 operator*(const M22 &p) const {
4 |     return (M22){a*p.a+b*p.c, a*p.b+b*p.d, c*p.a+d*p.c,c*p.b+d*p.d};}
5 | };
6 | M22 operator^(const M22 &p, int n){
7 |   if(!n) return (M22){1, 0, 0, 1}; //identidad
8 |   M22 q=p^(n/2); q=q*q;
9 |   return n%2? p * q : q;}
10 |
11 | ll fibo(ll n){ //calcula el fibonacci enesimo
12 |   M22 mat=(M22){0, 1, 1, 1}^n;
13 |   return mat.a*f0+mat.b*f1; //f0 y f1 son los valores iniciales
14 | }

```

### 6.5. Teorema Chino del Resto

$$y = \sum_{j=1}^n (x_j * (\prod_{i=1, i \neq j}^n m_i)_{m_j}^{-1} * \prod_{i=1, i \neq j}^n m_i)$$

### 6.6. Funciones de primos

```

1 | ll numPrimeFactors (ll n){
2 |   ll rta = 0;
3 |   map<ll,ll> f=fact(n);
4 |   forall(it, f) rta += it->second;

```

```

5   return rta;
6 }
7
8 ll numDiffPrimeFactors (ll n){
9     ll rta = 0;
10    map<ll,ll> f=fact(n);
11    forall(it, f) rta += 1;
12    return rta;
13 }
14
15 ll sumPrimeFactors (ll n){
16     ll rta = 0;
17     map<ll,ll> f=fact(n);
18     forall(it, f) rta += it->first;
19     return rta;
20 }
21
22 ll numDiv (ll n){
23     ll rta = 1;
24     map<ll,ll> f=fact(n);
25     forall(it, f) rta *= (it->second + 1);
26     return rta;
27 }
28
29 ll sumDiv (ll n){
30     ll rta = 1;
31     map<ll,ll> f=fact(n);
32     forall(it, f) rta *= ((ll)pow((double)it->first, it->second + 1.0)-1)
33     / (it->first-1);
34     return rta;
35 }
36
37 ll eulerPhi (ll n){ // con criba: O(lg n)
38     ll rta = n;
39     map<ll,ll> f=fact(n);
40     forall(it, f) rta -= rta / it->first;
41     return rta;
42 }
43
44 ll eulerPhi2 (ll n){ // O (sqrt n)
45     ll r = n;
46     forr (i,2,n+1){
47         if ((ll)i*i > n)

```

```

47         break;
48         if (n % i == 0){
49             while (n%i == 0) n/=i;
50             r -= r/i;
51         }}
52     if (n != 1)
53         r-= r/n;
54     return r;
55 }

```

## 6.7. Phollard's Rho (rolando)

```

1
2 ll mulmod (ll a, ll b, ll c) { //returns (a*b)%c, and minimize overflow
3     ll x = 0, y = a%c;
4     while (b > 0){
5         if (b % 2 == 1) x = (x+y) % c;
6         y = (y*2) % c;
7         b /= 2;
8     }
9     return x % c;
10 }
11
12 bool es_primo_prob (ll n, int a)
13 {
14     if (n == a)
15         return true;
16     ll s = 0, d = n-1;
17     while (d % 2 == 0) s++,d/=2;
18
19     ll x = expmod(a,d,n);
20     if ((x == 1) || (x+1 == n)) return true;
21
22     forn (i, s-1){
23         x = (x*x)%n;
24         if (x == 1) return false;
25         if (x+1 == n) return true;
26     }
27     return false;
28 }
29
30 bool miller_rabin (ll n){ //devuelve true si n es primo
31     const int ar[] = {2,3,5,7,11,13,17,19,23};

```

```

32  forn (j,9)
33      if (!es_primo_prob(n,ar[j]))
34          return false;
35  return true;
36 }
37
38 ll pollard_rho (ll n){
39     int i = 0, k = 2;
40     ll x = 3, y = 3;
41     while (1){
42         i++;
43         x = (mulmod (x,x,n) + n - 1) % n;
44         ll d = gcd (abs(y-x), n);
45         if(d==n) return -1;//FAILURE
46         if (d != 1) return d;
47         if (i == k) y = x, k*=2;
48     }
49 }

```

## 6.8. Criba

```

1  #define MAXP 80000 //no necesariamente primo
2  int criba[MAXP+1];
3  vector<int> primos;
4  void buscarprimos(){
5      int sq=sqrt(MAXP)+1;
6      forr(p, 2, MAXP+1) if(!criba[p]){
7          primos.push_back(p);
8          if(p<=sq)
9              for(int m=p*p; m<=MAXP; m+=p)//borro los multiples de p
10                 if(!criba[m])criba[m]=p;
11      }
12 }

```

## 6.9. Factorizacion

Sea  $n = \prod p_i^{k_i}$ , fact(n) genera un map donde a cada  $p_i$  le asocia su  $k_i$

```

1  //factoriza bien numeros hasta MAXP^2
2  map<ll,ll> fact(ll n){ //0 (cant primos)
3      map<ll,ll> ret;
4      forall(p, primos){
5          while(!(n%p)){
6              ret[*p]++;//divisor found
7              n/=p;

```

```

8      }
9      }
10     if(n>1) ret[n]++;
11     return ret;
12 }
13
14 //factoriza bien numeros hasta MAXP
15 map<ll,ll> fact2(ll n){ //0 (lg n)
16     map<ll,ll> ret;
17     while (criba[n]){
18         ret[criba[n]]++;
19         n/=criba[n];
20     }
21     if(n>1) ret[n]++;
22     return ret;
23 }

```

## 6.10. GCD

```

1  tipo gcd(tipo a, tipo b){return a?gcd(b %a, a):b;}

```

## 6.11. LCM

```

1  tipo lcm(tipo a, tipo b){return a / gcd(a,b) * b;}

```

## 6.12. Inversos

```

1  #define MAXMOD 15485867
2  ll inv[MAXMOD];//inv[i]*i=1 mod MOD
3  void calc(int p){//0(p)
4      inv[1]=1;
5      forr(i, 2, p) inv[i]= p-((p/i)*inv[p%i])%p;
6  }
7  int inverso(int x){//0(log x)
8      return expmod(x, eulerphi(MOD)-2);//si mod no es primo(sacar a mano)
9      return expmod(x, MOD-2);//si mod es primo
10 }

```

## 6.13. Simpson

```

1  double integral(double a, double b, int n=10000) { //0(n), n=cantdiv
2      double area=0, h=(b-a)/n, fa=f(a), fb;
3      forn(i, n){

```



```

4   fb=f(a+h*(i+1));
5   area+=fa+ 4*f(a+h*(i+0.5)) +fb, fa=fb;
6   }
7   return area*h/6.;}

```

### 6.14. Fraction

```

1 struct frac{
2   tipo p,q;
3   frac(tipo p=0, tipo q=1):p(p),q(q) {norm();}
4   tipo mcd(tipo a, tipo b){return a?mcd(b %a, a):b;}
5   void norm(){
6     tipo a = mcd(p,q);
7     if(a) p/=a, q/=a;
8     else q=1;
9     if (q<0) q=-q, p=-p;}
10  frac operator+(const frac& o){
11    tipo a = mcd(q,o.q);
12    return frac(p*(o.q/a)+o.p*(q/a), q*(o.q/a));}
13  frac operator-(const frac& o){
14    tipo a = mcd(q,o.q);
15    return frac(p*(o.q/a)-o.p*(q/a), q*(o.q/a));}
16  frac operator*(frac o){
17    tipo a = mcd(q,o.p), b = mcd(o.q,p);
18    return frac((p/b)*(o.p/a), (q/a)*(o.q/b));}
19  frac operator/(frac o){
20    tipo a = mcd(q,o.q), b = mcd(o.p,p);
21    return frac((p/b)*(o.q/a), (q/a)*(o.p/b));}
22  bool operator<(const frac &o) const{return p*o.q < o.p*q;}
23  bool operator==(frac o){return p==o.p&&q==o.q;}
24 };

```

### 6.15. Polinomio

```

1 #define MAX_GR 20
2 struct poly {
3   tipo p[MAX_GR]; //guarda los coeficientes del polinomio
4   poly(){zero(p);}
5   int gr(){//calculates grade of the polynomial
6     dforn(i,MAX_GR) if(p[i]) return i;
7     return 0; }
8   bool isnull() {return gr()==0 && !p[0];}
9   poly operator+(poly b) { // - is analogous
10    poly c=THIS;

```

```

11   forn(i,MAX_GR) c.p[i]+=b.p[i];
12   return c;
13 }
14 poly operator*(poly b) {
15   poly c;
16   forn(i,MAX_GR) forn(k,i+1) c.p[i]+=p[k]*b.p[i-k];
17   return c;
18 }
19 tipo eval(tipo v) {
20   tipo sum = 0;
21   dforn(i, MAX_GR) sum=sum*v + p[i];
22   return sum;
23 }
24 //the following function generates the roots of the polynomial
25 //it can be easily modified to return float roots
26 set<tipo> roots(){
27   set<tipo> roots;
28   tipo a0 = abs(p[0]), an = abs(p[gr()]);
29   vector<tipo> ps,qs;
30   forr(p,1,sqrt(a0)+1) if (a0%p==0) ps.pb(p),ps.pb(a0/p);
31   forr(q,1,sqrt(an)+1) if (an%q==0) qs.pb(q),qs.pb(an/q);
32   forall(pt,ps)
33     forall(qt,qs) if ( (*pt) % (*qt)==0 ) {
34       tipo root = abs((*pt) / (*qt));
35       if (eval(root)==0) roots.insert(root);
36     }
37   return roots;
38 }
39 };
40 //the following functions allows parsing an expression like
41 //34+150+4*45
42 //into a polynomial(el numero en funcion de la base)
43 #define LAST(s) (sz(s)? s[sz(s)-1] : 0)
44 #define POP(s) s.erase(--s.end());
45 poly D(string &s) {
46   poly d;
47   for(int i=0; isdigit(LAST(s)); i++) d.p[i]=LAST(s)-'0', POP(s);
48   return d;}
49
50 poly T(string &s) {
51   poly t=D(s);
52   if (LAST(s)=='*'){POP(s); return T(s)*t;}
53   return t;

```

```

54 }
55 //main function, call this to parse
56 poly E(string &s) {
57     poly e=T(s);
58     if (LAST(s)=='+'){POP(s); return E(s)+e;}
59     return e;
60 }

```

## 7. Grafos

### 7.1. Dijkstra

```

1  #define INF 1e9
2  int N;
3  #define MAX_V 250001
4  vector<ii> G[MAX_V];
5  //To add an edge use
6  #define add(a, b, w) G[a].pb(mkp(w, b))
7
8  ll dijkstra(int s, int t){//O(|E| log |V|)
9      priority_queue<ii, vector<ii>, greater<ii> > Q;
10     vector<ll> dist(N, INF); vector<int> dad(N, -1);
11     Q.push(mkp(0, s)); dist[s] = 0;
12     while(sz(Q)){
13         ii p = Q.top(); Q.pop();
14         if(p.snd == t) break;
15         forall(it, G[p.snd])
16             if(dist[p.snd]+it->first < dist[it->snd]){
17                 dist[it->snd] = dist[p.snd] + it->fst;
18                 dad[it->snd] = p.snd;
19                 Q.push(mkp(dist[it->snd], it->snd));
20             }
21     }
22     return dist[t];
23     if(dist[t]<INF)//path generator
24         for(int i=t; i!=-1; i=dad[i])
25             printf("%d%c", i, (i==s?'\\n':' '));
26 }

```

### 7.2. Bellman-Ford

```

1  vector<ii> G[MAX_N]; //ady. list with pairs (weight, dst)
2  int dist[MAX_N];

```

```

3  void bford(int src){//O(VE)
4      dist[src]=0;
5      forn(i, N-1) forn(j, N) if(dist[j]!=INF) forall(it, G[j])
6          dist[it->snd]=min(dist[it->snd], dist[j]+it->fst);
7  }
8
9  bool hasNegCycle(){
10     forn(j, N) if(dist[j]!=INF) forall(it, G[j])
11         if(dist[it->snd]>dist[j]+it->fst) return true;
12     //inside if: all points reachable from it->snd will have -INF distance
13     (do bfs)
14     return false;
15 }

```

### 7.3. Floyd-Warshall

```

1  //G[i][j] contains weight of edge (i, j) or INF
2  //G[i][i]=0
3  int G[MAX_N][MAX_N];
4  void floyd(){//O(N^3)
5      forn(k, N) forn(i, N) if(G[i][k]!=INF) forn(j, N) if(G[k][j]!=INF)
6          G[i][j]=min(G[i][j], G[i][k]+G[k][j]);
7  }
8  bool inNegCycle(int v){
9      return G[v][v]<0;}
10 //checks if there's a neg. cycle in path from a to b
11 bool hasNegCycle(int a, int b){
12     forn(i, N) if(G[a][i]!=INF && G[i][i]<0 && G[i][b]!=INF)
13         return true;
14     return false;
15 }

```

### 7.4. Kruskal

```

1  struct Ar{int a,b,w;};
2  bool operator<(const Ar& a, const Ar &b){return a.w<b.w;}
3  vector<Ar> E;
4  ll kruskal(){
5      ll cost=0;
6      sort(E.begin(), E.end()); //ordenar aristas de menor a mayor
7      uf.init(n);
8      forall(it, E){
9          if(uf.comp(it->a)!=uf.comp(it->b)){//si no estan conectados
10             uf.unir(it->a, it->b); //conectar

```

```

11         cost+=it->w;
12     }
13 }
14 return cost;
15 }

```

## 7.5. Prim

```

1 bool taken[MAXN];
2 priority_queue<ii, vector<ii>, greater<ii> > pq; //min heap
3 void process(int v){
4     taken[v]=true;
5     forall(e, G[v])
6         if(!taken[e->second]) pq.push(*e);
7 }
8
9 ll prim(){
10     zero(taken);
11     process(0);
12     ll cost=0;
13     while(sz(pq)){
14         ii e=pq.top(); pq.pop();
15         if(!taken[e.second]) cost+=e.first, process(e.second);
16     }
17     return cost;
18 }

```

## 7.6. 2-SAT + Tarjan SCC

```

1 //We have a vertex representing a var and other for his negation.
2 //Every edge stored in G represents an implication. To add an equation
3   of the form a||b, use addor(a, b)
4 //MAX=max cant var, n=cant var
5 #define addor(a, b) (G[neg(a)].pb(b), G[neg(b)].pb(a))
6 vector<int> G[MAX*2];
7 //idx[i]=index assigned in the dfs
8 //lw[i]=lowest index(closer from the root) reachable from i
9 int lw[MAX*2], idx[MAX*2], qidx;
10 stack<int> q;
11 int qcmp, cmp[MAX*2];
12 //verdad[cmp[i]]=valor de la variable i
13 bool verdad[MAX*2+1];
14 int neg(int x) { return x>=n? x-n : x+n;}

```

```

15 void tjn(int v){
16     lw[v]=idx[v]=++qidx;
17     q.push(v), cmp[v]=-2;
18     forall(it, G[v]){
19         if(!idx[*it] || cmp[*it]==-2){
20             if(!idx[*it]) tjn(*it);
21             lw[v]=min(lw[v], lw[*it]);
22         }
23     }
24     if(lw[v]==idx[v]){
25         qcmp++;
26         int x;
27         do{x=q.top(); q.pop(); cmp[x]=qcmp;}while(x!=v);
28         verdad[qcmp]=(cmp[neg(v)]<0);
29     }
30 }
31 //remember to CLEAR G!!!
32 bool satisf(){//O(n)
33     memset(idx, 0, sizeof(idx)), qidx=0;
34     memset(cmp, -1, sizeof(cmp)), qcmp=0;
35     forn(i, n){
36         if(!idx[i]) tjn(i);
37         if(!idx[neg(i)]) tjn(neg(i));
38     }
39     forn(i, n) if(cmp[i]==cmp[neg(i)]) return false;
40     return true;
41 }

```

## 7.7. Articulation Points

```

1 int N;
2 vector<int> G[1000000];
3 //V[i]=node number(if visited), L[i]= lowest V[i] reachable from i
4 int qV, V[1000000], L[1000000], P[1000000];
5 void dfs(int v, int f){
6     L[v]=V[v]=++qV;
7     forall(it, G[v])
8         if(!V[*it]){
9             dfs(*it, v);
10            L[v] = min(L[v], L[*it]);
11            P[v] += L[*it]>=V[v];
12        }
13     else if(*it!=f)

```

```

14     L[v]=min(L[v], V[*it]);
15 }
16 int cantart(){ //O(n)
17     qV=0;
18     zero(V), zero(P);
19     dfs(1, 0); P[1]--;
20     int q=0;
21     forn(i, N) if(P[i]) q++;
22     return q;
23 }

```

## 7.8. Comp. Biconexas y Puentes

```

1 struct edge {
2     int u,v, comp;
3     bool bridge;
4 };
5 vector<edge> e;
6 void addEdge(int u, int v) {
7     G[u].pb(sz(e)), G[v].pb(sz(e));
8     e.pb((edge){u,v,-1,false});
9 }
10 //d[i]=id de la dfs
11 //b[i]=lowest id reachable from i
12 int d[MAXN], b[MAXN], t;
13 int nbc;//cant componentes
14 int comp[MAXN];//comp[i]=cant comp biconexas a la cual pertenece i
15 void initDfs(int n) {
16     zero(G), zero(comp);
17     e.clear();
18     forn(i,n) d[i]=-1;
19     nbc = t = 0;
20 }
21 stack<int> st;
22 void dfs(int u, int pe) { //O(n + m)
23     b[u] = d[u] = t++;
24     comp[u] = (pe != -1);
25     forall(ne, G[u]) if (*ne != pe){
26         int v = e[*ne].u ^ e[*ne].v ^ u;
27         if (d[v] == -1) {
28             st.push(*ne);
29             dfs(v,*ne);
30             if (b[v] > d[u]){

```

```

31         e[*ne].bridge = true; // bridge
32     }
33     if (b[v] >= d[u]){ // art
34         int last;
35         do {
36             last = st.top(); st.pop();
37             e[last].comp = nbc;
38         } while (last != *ne);
39         nbc++;
40         comp[u]++;
41     }
42     b[u] = min(b[u], b[v]);
43 }
44 else if (d[v] < d[u]) { // back edge
45     st.push(*ne);
46     b[u] = min(b[u], d[v]);
47 }
48 }
49 }

```

## 7.9. LCA + Climb

```

1 //f[v][k] holds the 2^k father of v
2 //L[v] holds the level of v
3 int N, f[100001][20], L[100001];
4 void build(){//f[i][0] must be filled previously, O(nlgn)
5     forn(k, 20-1) forn(i, N) f[i][k+1]=f[f[i][k]][k];}
6
7 #define lg(x) (31-__builtin_clz(x))//=floor(log2(x))
8
9 int climb(int a, int d){//O(lgn)
10     if(!d) return a;
11     dforn(i, lg(L[a])+1)
12         if(1<<i<=d)
13             a=f[a][i], d-=1<<i;
14     return a;
15 }
16 int lca(int a, int b){//O(lgn)
17     if(L[a]<L[b]) swap(a, b);
18     a=climb(a, L[a]-L[b]);
19     if(a==b) return a;
20     dforn(i, lg(L[a])+1)
21         if(f[a][i]!=f[b][i])

```

```

22     a=f[a][i], b=f[b][i];
23     return f[a][0];
24 }

```

## 7.10. Heavy Light Decomposition

```

1  int treesz[MAXN]; //cantidad de nodos en el subarbol del nodo v
2  int dad[MAXN]; //dad[v]=padre del nodo v
3  void dfs1(int v, int p=-1) { //pre-dfs
4      dad[v]=p;
5      treesz[v]=1;
6      forall(it, G[v]) if(*it!=p){
7          dfs1(*it, v);
8          treesz[v]+=treesz[*it];
9      }
10 }
11 int pos[MAXN], q; //pos[v]=posicion del nodo v en el recorrido de la dfs
12 //Las cadenas aparecen continuas en el recorrido!
13 int cantcad;
14 int homecad[MAXN]; //dada una cadena devuelve su nodo inicial
15 int cad[MAXN]; //cad[v]=cadena a la que pertenece el nodo
16 void heavylight(int v, int cur=-1){
17     if(cur==--1) homecad[cur=cantcad++] = v;
18     pos[v]=q++;
19     cad[v]=cur;
20     int mx=-1;
21     forn(i, sz(G[v])) if(G[v][i]!=dad[v]){
22         if(mx==--1 || treesz[G[v][mx]]<treesz[G[v][i]]) mx=i;
23         if(mx!=-1) heavylight(G[v][mx], cur);
24         forn(i, sz(G[v])) if(i!=mx && G[v][i]!=dad[v]){
25             heavylight(G[v][i], -1);
26         }
27     } //ejemplo de obtener el maximo numero en el camino entre dos nodos
28     //RTA: max(query(low, u), query(low, v)), con low=lca(u, v)
29     //esta funcion va trepando por las cadenas
30     int query(int an, int v) { //O(logn)
31         //si estan en la misma cadena:
32         if(cad[an]==cad[v]) return rmq.get(pos[an], pos[v]+1);
33         return max(query(an, dad[homecad[cad[v]]]),
34             rmq.get(pos[homecad[cad[v]]], pos[v]+1));
35     }

```

## 8. Network Flow

### 8.1. Dinic

```

1  int nodes, src, dest;
2  int dist[MAX], q[MAX], work[MAX];
3
4  struct Edge {
5      int to, rev;
6      ll f, cap;
7      Edge(int to, int rev, ll f, ll cap) : to(to), rev(rev), f(f), cap(cap)
8          {}
9  };
10 vector<Edge> G[MAX];
11
12 // Adds bidirectional edge
13 void addEdge(int s, int t, ll cap){
14     G[s].push_back(Edge(t, G[t].size(), 0, cap));
15     G[t].push_back(Edge(s, G[s].size()-1, 0, 0));
16 }
17
18 bool dinic_bfs() {
19     fill(dist, dist + nodes, -1);
20     dist[src] = 0;
21     int qt = 0;
22     q[qt++] = src;
23     for (int qh = 0; qh < qt; qh++) {
24         int u = q[qh];
25         forall(e, G[u]){
26             int v = e->to;
27             if(dist[v]<0 && e->f < e->cap){
28                 dist[v]=dist[u]+1;
29                 q[qt++]=v;
30             }
31         }
32     }
33     return dist[dest] >= 0;
34 }
35
36 ll dinic_dfs(int u, ll f) {
37     if (u == dest) return f;
38     for (int &i = work[u]; i < (int) G[u].size(); i++) {

```

```

39   Edge &e = G[u][i];
40   if (e.cap <= e.f) continue;
41   int v = e.to;
42   if (dist[v] == dist[u] + 1) {
43       ll df = dinic_dfs(v, min(f, e.cap - e.f));
44       if (df > 0) {
45           e.f += df;
46           G[v][e.rev].f -= df;
47           return df;
48       }
49   }
50 }
51 return 0;
52 }
53
54 ll maxFlow(int _src, int _dest) { //O(V^2 E) <
55     src = _src;
56     dest = _dest;
57     ll result = 0;
58     while (dinic_bfs()) {
59         fill(work, work + nodes, 0);
60         while (ll delta = dinic_dfs(src, INF))
61             result += delta;
62     }
63
64     // todos los nodos con dist[v] != -1 vs los que tienen dist[v] == -1
65     // forman el min cut
66
67     return result;
68 }

```

## 8.2. König

```

1 // asume que el dinic YA ESTA tirado
2 // asume que nodes-1 y nodes-2 son la fuente y destino
3 int match[maxnodes]; // match[v]=u si u-v esta en el matching, -1 si v
4 // no esta matcheado
5 int s[maxnodes]; // numero de la bfs del koning
6 queue<int> kq;
7 // s[e]%2==1 o si e esta en V1 y s[e]==-1-> lo agarras
8 void koning() { //O(n)
9     for (v, nodes-2) s[v] = match[v] = -1;
10    for (v, nodes-2) for (it, g[v]) if (it->to < nodes-2 && it->f > 0)

```

```

10    { match[v]=it->to; match[it->to]=v; }
11    for (v, nodes-2) if (match[v]==-1) { s[v]=0; kq.push(v); }
12    while (!kq.empty()) {
13        int e = kq.front(); kq.pop();
14        if (s[e]%2==1) {
15            s[match[e]] = s[e]+1;
16            kq.push(match[e]);
17        } else {
18
19            for (it, g[e]) if (it->to < nodes-2 && s[it->to]==-1) {
20                s[it->to] = s[e]+1;
21                kq.push(it->to);
22            }
23        }
24    }
25 }

```

## 8.3. Edmonds Karp's

```

1 #define MAX_V 1000
2 #define INF 1e9
3 //special nodes
4 #define SRC 0
5 #define SNK 1
6 map<int, int> G[MAX_V]; //limpiar esto
7 //To add an edge use
8 #define add(a, b, w) G[a][b]=w
9 int f, p[MAX_V];
10 void augment(int v, int minE){
11     if (v==SRC) f=minE;
12     else if (p[v] != -1){
13         augment(p[v], min(minE, G[p[v]][v]));
14         G[p[v]][v] -= f, G[v][p[v]] += f;
15     }
16 }
17 ll maxflow() { //O(VE^2)
18     ll Mf=0;
19     do{
20         f=0;
21         char used[MAX_V]; queue<int> q; q.push(SRC);
22         zero(used), memset(p, -1, sizeof(p));
23         while (sz(q)){
24             int u=q.front(); q.pop();

```

```

25     if(u==SNK) break;
26     forall(it, G[u])
27         if(it->snd>0 && !used[it->fst])
28             used[it->fst]=true, q.push(it->fst), p[it->fst]=u;
29     }
30     augment(SNK, INF);
31     Mf+=f;
32 }while(f);
33 return Mf;
34 }

```

#### 8.4. Push-Relabel

```

1  #define MAX_V 1000
2  int N;//valid nodes are [0...N-1]
3  #define INF 1e9
4  //special nodes
5  #define SRC 0
6  #define SNK 1
7  map<int, int> G[MAX_V];
8  //To add an edge use
9  #define add(a, b, w) G[a][b]=w
10 ll excess[MAX_V];
11 int height[MAX_V], active[MAX_V], count[2*MAX_V+1];
12 queue<int> Q;
13 void enqueue(int v) {
14     if (!active[v] && excess[v] > 0) active[v]=true, Q.push(v); }
15 void push(int a, int b) {
16     int amt = min(excess[a], ll(G[a][b]));
17     if(height[a] <= height[b] || amt == 0) return;
18     G[a][b]-=amt, G[b][a]+=amt;
19     excess[b] += amt, excess[a] -= amt;
20     enqueue(b);
21 }
22 void gap(int k) {
23     forn(v, N){
24         if (height[v] < k) continue;
25         count[height[v]]--;
26         height[v] = max(height[v], N+1);
27         count[height[v]]++;
28         enqueue(v);
29     }
30 }

```

```

31 void relabel(int v) {
32     count[height[v]]--;
33     height[v] = 2*N;
34     forall(it, G[v])
35         if(it->snd)
36             height[v] = min(height[v], height[it->fst] + 1);
37     count[height[v]]++;
38     enqueue(v);
39 }
40 ll maxflow() { //O(V^3)
41     zero(height), zero(active), zero(count), zero(excess);
42     count[0] = N-1;
43     count[N] = 1;
44     height[SRC] = N;
45     active[SRC] = active[SNK] = true;
46     forall(it, G[SRC]){
47         excess[SRC] += it->snd;
48         push(SRC, it->fst);
49     }
50     while(sz(Q)) {
51         int v = Q.front(); Q.pop();
52         active[v]=false;
53         forall(it, G[v]) push(v, it->fst);
54         if(excess[v] > 0)
55             count[height[v]] == 1? gap(height[v]):relabel(v);
56     }
57     ll mf=0;
58     forall(it, G[SRC]) mf+=G[it->fst][SRC];
59     return mf;
60 }

```

#### 8.5. Min-cost Max-flow

```

1  struct edge {
2      int u, v;
3      ll cap, cost, flow;
4      ll rem() { return cap - flow; }
5  };
6  int n;//numero de nodos
7  vector<int> G[MAXN];
8  vector<edge> e;
9  void addEdge(int u, int v, ll cap, ll cost) {
10     G[u].pb(si(e)); e.pb((edge){u,v,cap,cost,0});

```

```

11  G[v].pb(si(e)); e.pb((edge){v,u,0,-cost,0});
12  }
13  ll pot[MAXN], dist[MAXN], pre[MAXN], cap[MAXN];
14  ll mxFlow, mnCost;
15  void flow(int s, int t) {
16      fill(pot, pot+n, 0);
17      mxFlow=mnCost=0;
18      while(1){
19          fill(dist, dist+n, INF); dist[s] = 0;
20          fill(pre, pre+n, -1); pre[s]=0;
21          fill(cap, cap+n, 0); cap[s] = INF;
22          priority_queue<pair<ll,int> > q; q.push(mkp(0,s));
23          while (!q.empty()) {
24              pair<ll,int> top = q.top(); q.pop();
25              int u = top.second, d = -top.first;
26              if (u == t) break;
27              if (d > dist[u]) continue;
28              forn(i,si(G[u])) {
29                  edge E = e[G[u][i]];
30                  int c = E.cost + pot[u] - pot[E.v];
31                  if (E.rem() && dist[E.v] > dist[u] + c) {
32                      dist[E.v] = dist[u] + c;
33                      pre[E.v] = G[u][i];
34                      cap[E.v] = min(cap[u], E.rem());
35                      q.push(mkp(-dist[E.v], E.v));
36                  }
37              }
38          }
39          if (pre[t] == -1) break;
40          for (int v = t; v != s; v = e[pre[v]].u) {
41              e[pre[v]].flow += cap[t];
42              e[pre[v]^1].flow -= cap[t];
43          }
44          mxFlow +=cap[t];
45          mnCost +=cap[t]*(dist[t]-pot[s]+pot[t]);
46          forn(u,n)
47              if (dist[u] == INF) pot[u] = INF;
48              else pot[u] += dist[u];
49      }
50  }

```

## 9. Ayudamemoria

### Límites

```
1 #include <climits> //INT_MIN, LONG_MAX, ULLONG_MAX, etc.
```

### Cant. decimales

```
1 #include <iomanip>
2 cout << setprecision(2) << fixed;
```

### Rellenar con espacios(para justificar)

```
1 #include <iomanip>
2 cout << setfill('␣') << setw(3) << 2 << endl;
```

### Leer hasta fin de línea

```
1 #include <sstream>
2 //hacer cin.ignore() antes de getline()
3 while(getline(cin, line)){
4     istringstream is(line);
5     while(is >> X)
6         cout << X << "␣";
7     cout << endl;
8 }
```

### Aleatorios

```
1 #define RAND(a, b) (rand()%(b-a+1)+a)
2 srand(time(NULL));
```

### Doubles Comp.

```
1 const double EPS = 1e-9;
2 x == y <=> fabs(x-y) < EPS
3 x > y <=> x > y + EPS
4 x >= y <=> x > y - EPS
```

### Límites

```
1 #include <limits>
2 numeric_limits<T>
3     ::max()
4     ::min()
5     ::epsilon()
```



## Muahaha

```
1 | #include <signal.h>
2 | void divzero(int p){
3 |     while(true);}
4 | void segm(int p){
5 |     exit(0);}
6 | //in main
7 | signal(SIGFPE, divzero);
8 | signal(SIGSEGV, segm);
```

## Mejorar velocidad

```
1 | ios::sync_with_stdio(false);
```

## Mejorar velocidad 2

```
1 | //Solo para enteros positivos
2 | inline void Scanf(int& a){
3 |     char c = 0;
4 |     while(c<33) c = getc(stdin);
5 |     a = 0;
6 |     while(c>33) a = a*10 + c - '0', c = getc(stdin);
7 | }
```

## Leer del teclado

```
1 | freopen("/dev/tty", "a", stdin);
```

## File setup

```
1 | //tambien se pueden usar comas: {a, x, m, l}
2 | for i in {a..k}; do cp template.cpp $i.cpp && touch $i.in; done
```